

Acoustic Monitoring on the Fred Hartman Bridge

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Abstract

The stay cables of the Fred Hartman Bridge have undergone thousands of wind- and rain-induced oscillations since the bridge opened in 1995. TxDOT is investigating these oscillations in several ways—including sponsoring research—to determine specific causes, to identify their effect on the stay cables, and to guide development of a cable retrofit if one becomes necessary to eliminate the oscillations. TxDOT has also implemented an acoustic monitoring program to “listen” to the structure in ways that can identify any breaking of the strands of the stay cables. This paper reports on TxDOT investigations to date, particularly on the testing and implementation of the acoustic monitoring system now installed on the bridge.

Introduction

In 1995 a new bridge was opened to traffic crossing the Houston Ship Channel in Texas. (See Figure 1.) The Fred Hartman Bridge crosses the Houston Ship Channel and is between Baytown and LaPorte on State Highway 146. Its superstructure includes twin 78-foot wide composite concrete decks, each supported on steel plate girders. One hundred and ninety-two stay cables fan out from four diamond-shaped concrete towers to support the superstructure on the outsides of each deck.



Figure 1. The Fred Hartman Bridge

Initial Reports

Soon after the bridge opened to service, users began noticing large amplitude stay-cable oscillations, usually during rain and light winds. Following up on the reports, Texas Department

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of Transportation (TxDOT) inspection personnel discovered cracking in welds of steel transition pipes connecting the stay cables to the superstructure, and they attributed the cracking to cyclic loading from the oscillations. TxDOT immediately initiated investigation into the serviceability and long-term durability of the stay cable system. The investigation focused on fatigue of the steel strands in the stay cable, but cracking of the protective grout in the stay cable was also a concern. (See Figure 2.)



Figure 2. Fred Hartman Bridge Stay Cable Anchor

TxDOT Response

Recognizing the need for additional information, TxDOT developed a plan to collect data about the performance of the stay cables, particularly under oscillation, so that an effective retrofit could be designed. The plan had a three-pronged approach:

- Collecting information on the events that influenced the oscillations.
- Determining the effect of excessive oscillations on stay-cable service life.
- Setting up acoustic monitoring to identify damage occurring to the stay cables.

The first part of the plan was conducted through a research project with Texas Tech University (TTU). In conjunction with Johns Hopkins University, TTU developed a remote monitoring system to collect information about cable movement with corresponding rain and wind data. This information was supplemented with wind tunnel studies on scale models of the stay cables and used to identify factors that were responsible for initiating the stay-cable vibrations. Researchers used remote monitoring of the bridge to refine their design for proposed dampers that to be installed on the bridge.

The second part of the plan is being addressed by TxDOT-sponsored research conducted by the University of Texas at Austin, and it involves cyclic loading of full-scale stay cables in bending to determine the relationship between stress amplitude and fatigue damage. To date, four specimens have been tested and four more tests are proposed. From this study the researchers

have a better understanding about the stiffness of the strands and the contribution of the grout to the cable stiffness. Future work will evaluate what influence cable restrainers and dampers, similar to those that are being proposed for installation on the Fred Hartman Bridge, will have on the stay cables.

The third part of the plan developed when TxDOT began considering a proposal to install an acoustic monitoring system to detect wire breaks caused by cyclic loading of stay cables. TxDOT had two areas of concern requiring evaluation before any permanent installation of instruments:

- Not much is known about the reliability of monitoring grouted cable stays with an acoustic system.
- Local electrical storms, proximity to chemical plants, and a salt air environment posed possible threats to the durability of any electrical monitoring system that might be installed on the bridge.

In order to determine the reliability of acoustic monitoring, the stay cable fatigue research project at the University of Texas Ferguson Lab was modified to include installation and evaluation of the proposed system.

Laboratory Installation: Reliability Study at the University of Texas

TxDOT decided to monitor acoustically a cable that was being fatigue tested at the University of Texas' Ferguson Lab in order to determine the reliability of the acoustic monitoring system. Researchers built the test cable to resemble the shortest stay cable on the Fred Hartman Bridge. The test cable consists of 19 seven-wire strands wrapped in a helical spacer and placed in a 4.5-inch polyethylene pipe. As part of its preparation, the cable was stressed to 40% of the Guaranteed Ultimate Tensile Strength of 270 ksi and grouted.

Reliability Test Setup

Researchers installed the stressed and grouted cable into the loading and reaction frames and positioned the loading ram. (See Figure 3.) The loading ram was set to cycle the cable at an amplitude of ± 1.6 inches at a frequency of 0.7 to 0.9 Hz. Strain gauges were placed on the cable at the anchorage points, tension rings, and along the free length. Pure Technologies Ltd. placed acoustic monitoring sensors on the cable at four locations to determine if wire break events could be detected and located.

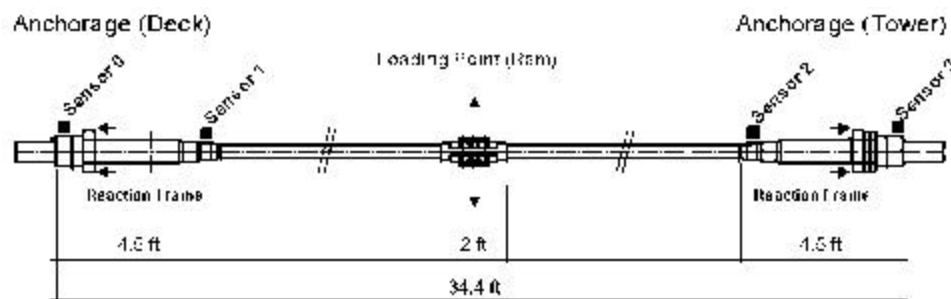


Figure 3. Test Setup with Acoustic Sensors

Reliability Test Results

During 2,800,000 cycles, the acoustic monitoring system registered 14 wire break events at the anchor representing the upper end of the stay at the tower and 11 breaks at the loading point. Pure Technologies Ltd. triangulated each point using data from the four gauges. The cable was then cut into five seven-foot segments and autopsied to verify the position and location of wire breaks. The autopsy revealed 14 breaks within a 24-inch range from the tower anchor and 11 breaks within a 24-inch range from the loading point. Thirteen out of 14 wire breaks at the tower anchorage were found inside the range reported by Pure Technologies Ltd. The one remaining wire break was found 7 inches outside the reported range. Three out of 11 wire breaks under the loading point were found inside the reported range. The eight remaining wire breaks were all found within 8 inches outside of the reported range, towards the deck side.

Field Installation: Durability Study at the Fred Hartman Bridge

To determine the durability of the system, TxDOT staff placed three sensors on one of the stay cables on the Fred Hartman Bridge. They installed sensors and monitored the data acquisition system to determine whether the system could be maintained in a real world application and whether it could withstand natural elements such as extreme heat, rain, and lightning strikes. The system was operational from February 7, 2001, to May 31, 2001, and during this time it was operational 99.4% of the time.

Implementation of Acoustic Monitoring of the Fred Hartman Bridge

Full implementation of acoustic monitoring of the Fred Hartman Bridge began in April 2002. TxDOT contracted with Pure Technologies Ltd. to install the SoundPrint® system to detect and locate failures in the stay cables. Three acoustic sensors were attached to each stay cable: one at the deck anchorage, one above the anchorage near deck level, and one at the tower anchorage. (See Figure 4.) A total of 576 sensors were installed to monitor all 192 stay cables. The sensors were attached to the anchors and cable stays with epoxy and strapping. Twisted pair cable was run from each sensor through conduit, to protect it from the elements, vandalism and other construction and maintenance hazards, to the data acquisition unit located in one of the pylon legs. (See Figure 5.) Telephone service and electrical power was also provided to the data acquisition unit.



Figure 4. Acoustic Sensor Installed on Stay Cable



Figure 5. Acoustic Monitoring Data Acquisition Unit

Screening of Acoustic Events

An acoustic survey of the bridge was then conducted to provide information on normal acoustic activity such as highway noise. The on-site computer filters out ambient noise before identifying and passing information on events to the central data processing unit via a telephone line. At the central data processing unit, the data is compared to known acoustic properties of wire breaks and is classified as follows:

- Anchorage Noise – Ambient noise occurring at the anchorage.
- Electrical Noise – Electrical noise associated with the power supplied to the data acquisition system.
- Possible Wire Break – Events that contain some but not all the characteristics of a wire break event.
- Construction Activity – An event associated with known construction activity.
- Schmidt Hammer Impact – A known impact similar to one caused by Pure Technologies Ltd. with a Schmidt hammer when testing the monitoring system. A Schmidt hammer is a device capable of delivering an impact of a known amount of energy.
- Steel Ball Impact – A known impact similar to one caused by Pure Technologies Ltd. with a small steel ball when testing the monitoring system.
- Test Impact: Other – A known impact similar to one caused by Pure Technologies Ltd. when they tested the monitoring system.
- Wire Break – An event exhibiting all the characteristics of a wire break.

The times and locations of these events are recorded and presented on a web page that can be remotely monitored.

Notification

When the acoustic monitoring system identifies a wire break or possible wire break, key district and division personnel (District Bridge Engineer, District Maintenance Engineer, Area Engineer,

Bridge Division Field Operation Section Director, etc.) are notified by email, phone, or pager identifying when the event occurred and the location of the event. On June 25, 2002, Pure Technologies notified TxDOT personnel of a possible wire break on stay cable No. 6 on the South Tower of Line “D”(Stay D-6). (See Figures 6 and 7.) Although construction was underway on that day, TxDOT personnel verified that because of a rainstorm, no construction work was occurring at the time of the event. Additionally, personnel had noticed that during the rainstorm many of the stay cables were oscillating from the wind and rain.

TxDOT personnel inspected the upper anchorage of Stay D-6 but found no evidence of any structural problem associated with this wire break. “Pluck” testing of this stay to evaluate the stay force has also been performed. At this time, there is no indication of loss of force in this stay. The location of the event has been noted, and a more thorough investigation may be performed to determine the condition of the stay cable.

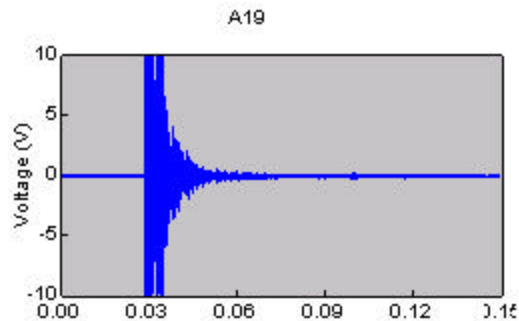


Figure 6. Acoustic Sound Print of a Wire Break

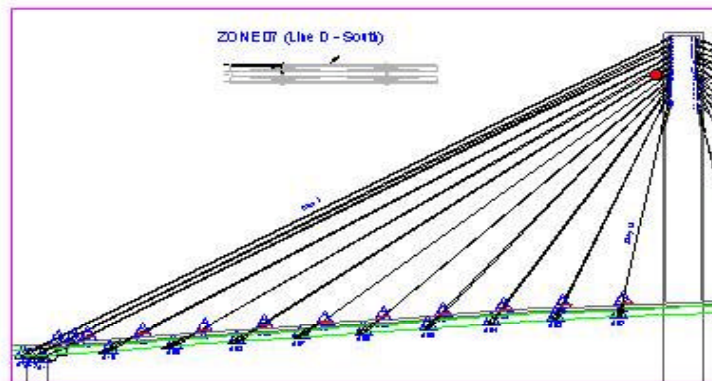


Figure 7. Wire Break Location

Future

TxDOT will continue to monitor the Fred Hartman Bridge stay cables with the acoustic monitoring system. Results will assist TxDOT engineers with the evaluation of the long-term performance of the stays and the effectiveness of the vibration damping system.

References. SoundPrint is a registered trademark of Pure Technologies Ltd.